by Mr. Blanford ('Nature,' vol. xii. p. 188), solar radiation is greater in the rainiest years, that is, in the years of most sun-spot. That the rainiest years should be the years of greatest solar radiation, is, as was argued in a paper read before the Meteorological Society of Mauritius on the 16th of January, 1873, what analogy would lead us to expect.

March 16, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Preliminary Reports to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Work done on board the 'Challenger.'" By John Murray, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

II. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Staff, on the true Corals dredged by H.M.S. 'Challenger,' in deep water, between the dates Dec. 30th, 1870, and August 31st, 1875." By H. N. Moseley, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

III. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Observations made during the earlier part of the Voyage." By the late Dr. Rudolf von Willemöes-Suhm, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

IV. "Preliminary Report to Professor Wyville Thomson, F.R.S., Director of the Civilian Scientific Staff, on Crustacea observed during the Cruise of H.M.S. 'Challenger' in the Southern Sea." By the late Dr. Rudolf von Willemöes-Suhm, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

V. "Preliminary Report to Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff, on Work (Chemical and Geological) done on board H.M.S. 'Challenger.'" By J. Y. BUCHANAN, Chemist and Physicist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received March 7, 1876.

[These Reports will appear in a subsequent Number of Proceedings.]

March 23, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On the Force caused by the Communication of Heat between a Surface and a Gas, and on a New Photometer." By Prof. OSBORNE REYNOLDS. Communicated by B. STEWART, F.R.S., Professor of Natural Philosophy in Owens College, Manchester. Received February 24, 1876.

(Abstract.)

This paper contains an account of an experimental investigation undertaken with a view to support, by absolute measurements, the theoretical arguments by which the author endeavoured to prove the existence of reactionary forces or "heat-reactions" whenever heat is communicated from a surface to a gas, and *vice versâ*, and the connexion between these forces and the motion caused by heat and light falling on bodies *in vacuo*.

Since the publication of the author's paper on this subject in the 'Proceedings' for April 1874, the correctness of his conclusions with regard to the existence of these heat-reactions has not been controverted or even questioned; while Professors Tait and Dewar, after an elaborate investigation, entirely confirm the author, not only in these conclusions, but also in his view as regards the explanation of Mr. Crookes's experiments. Mr. Crookes, however, appears entirely to repudiate this explanation, arguing,—

1. That he obtains his best results in vacua so perfect that there is no air either to receive the heat or react on the surface.

2. That the force is *radiant* in character.

3. That light, as well as heat, produces the motion, which consequently cannot be due to the heating of the surface.

Having obtained one of the beautiful little "light-mills" constructed by Dr. Geissler, of Bonn, the author was in a position to make quantitative measurements of the effects produced and of the force producing them.

In the first place, with regard to the sufficiency of the residual air to cause the motion. It was found that this air is, with the exception of the friction of the pivot, which is found to be so small as to be inappreciable, the sole cause of the resistance which the mill experiences, of the limit which is imposed on its speed for each intensity of light, and of the rapidity with which it comes to rest when the light is removed. The law of resistance, as determined by careful measurements, is found to agree perfectly with the resistance which highly rarefied air would offer to its motion; and this law is distinctly special in its character, being proportional to the velocity at low speeds, and gradually tending towards the square of the velocity as the speed increases.

Having established the fact that there is sufficient air in the mill (and Mr. Crookes's behaves in the same manner as this mill) to balance, by its resistance, the force which moves the mill, it is argued that all question as to the sufficiency of the air to cause the forces is removed. What the air can prevent it can cause.

As regards the possibility of the motion being in any way the direct result of radiation. This supposition the author had previously shown to be directly contradicted by the fundamental law of motion that action and reaction are equal. A cold body runs away from a hot body, while, if free to move, the hot body will run after the cold body, showing that the force does not act from body to body, but that each body propels itself through the surrounding medium in a direction opposite to its hottest side, the effect of one body on the other being due solely to the disturbance which it causes in the equilibrium of temperature.

The truth of this view was entirely confirmed by an experiment made by Dr. Schuster, to be communicated to the Royal Society. Dr. Schuster, by suspending the entire mill, was able to see whether the force which causes the vanes of the mill to revolve caused any twisting force on the envelope; and he found that such twisting force, so far as it existed, was exactly what must result from a force arising entirely within the mill, *i. e.* between the vanes and the medium immediately surrounding them. While the vanes were acquiring momentum a reaction was experienced by the envelope; but when the vanes had acquired full speed, the envelope was subjected to no force whatever; when, however, the light was turned off, the vanes, by virtue of the friction they experienced, tended to drag the envelope with them.

Besides proving that the force acts between the vanes of the mill and the medium immediately surrounding them, Dr. Schuster's experiments furnish a quantitative measure of the actual force. Taking the manner of suspension and the weight of the mill into consideration, the effect pro-

duced showed that, when making 240 revolutions per minute, the torsional force on the vanes does not exceed one forty millionth part of a pound acting on a lever a foot long; that the pressure of the gas on the vanes to produce this was not more than one two million five hundred thousandth part of a pound on the square inch, or one thousandth part of the pressure in a Torricellian vacuum, thus placing the extreme minuteness of the forces in a clear light, a light from which the extreme delicacy of Mr. Crookes's instrument had altogether withdrawn them.

It is then shown on theoretical grounds that the difference of temperature on the two sides of the vanes necessary to cause heat-reactions of this magnitude could not be less than 1°·7 F., while the probability is that it is considerably more.

In order to apply this test and see how far the actual difference of temperature in Dr. Schuster's experiments corresponded with that deduced from the theory, a new photometer was devised by the author with an immediate view of measuring the difference of temperature caused by light on a black and a white surface.

Of two thin glass globes, $2\frac{1}{2}$ inches in diameter, connected by a siphon-tube $\frac{1}{8}$ inch internal diameter, one was blackened with lamp-black on the inside over one hemisphere and the other was whitened with chalk in a similar manner, the two clean faces of the globes being turned in the same direction. Oil was put in the tube and the globes were otherwise sealed up. Any light which enters through the clean faces is received on the black and white surfaces, and the air in the globes expands in accordance with the difference of temperature which they attain, moving the oil in the tube. A motion of $\frac{1}{2}$ an inch on the part of the oil shows a difference of 2°·2 in the temperature of the air within the globes.

The instrument so constructed is exceedingly delicate, and will show a difference in the intensity of light sufficient to make one revolution per minute difference in the speed of the mill. As a photometer it is much more convenient than the mill, and its construction presents much less difficulty. By making the lower portion of the siphon-tube horizontal, and using glass indices after the manner of Rutherford's thermometer, the instrument might be made to record maxima and minima intensities of light, as well as be more delicate in other respects.

Measured with this instrument, the light necessary to give the mill 240 revolutions per minute does not exceed 24°, and is probably less than this, which shows that the theoretical difference of heat necessary to cause the heat-reactions is well within the difference as actually measured, leaving an ample margin for error in the methods of approximation used in the calculation.

In concluding the paper the author claims to have set at rest the only point respecting the explanation of the motion caused by heat which remained doubtful after he had discovered that, according to the kinetic

theory, the communication of heat to a gas must cause a force reactionary on the surface, viz. whether this reaction was adequate in amount to cause the results seen to take place.

He adds a suggestion as to a new form of light-mill to have vanes inclined like the sails of a windmill, and not having one side white and the other black, like the light-mills at present constructed, arguing that the forces act perpendicularly to the surface, and in a direction independent of that from which the light comes; so that such a mill would turn like a windmill with the full and not merely the differential effect of the light. Such a mill, he concludes, would furnish another test as to whether or not the force is directly referable to radiation.

II. "On the Nature of the Force producing the Motion of a Body exposed to Rays of Heat and Light." By Arthur Schuster, Ph.D., Demonstrator in the Physical Laboratory of Owens College. Communicated by B. Stewart, F.R.S., Professor of Natural Philosophy in Owens College, Manchester.

(Abstract.)

Mr. Crookes has lately drawn attention to the mechanical action of a source of light on delicately suspended bodies *in vacuo*; I have made a few experiments which will, I think, throw some light on the cause of the phenomenon, and assist us in the explanation of the manifold and striking experiments made by Mr. Crookes.

Whenever we observe a force tending to drive a body in a certain direction, we are sure to find a force equal in amount acting in the opposite direction on the body from which the force emanates. It was with the view of finding the seat of this reaction that I have made a few experiments.

If the force is directly due to radiation the reaction will be on the radiating body; if, on the other hand, it is due to any interior action, such as the one suggested by Prof. Reynolds, the reaction will be on the enclosure of the moving bodies. I have been able to test this by experiment, and I have found that the action and reaction is entirely between the light bodies suspended *in vacuo* and the exhausted vessel.

The instrument best fitted for an experimental investigation of this kind is the one which has been called "radiometer" by Mr. Crookes. These instruments have been made in great perfection by Dr. Geissler, of Bonn, under the name of "light-mills." Thanks to the courtesy of Prof. Reynolds, I have been enabled to work with such an instrument. The "light-mill" was suspended by means of two cocoon fibres, forming a bifilar suspension, from the top of a vessel which could be exhausted. A slight movement of the enclosure could be easily detected by means of a concave mirror attached to it. A beam of the oxyhydrogen lamp